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POSITION STATEMENT ON WATER MANAGEMENT TECHNIQUES

for

Working Group B

Guidelines and Criteria Review

Ministry of the Environment

Ontario

The Honourable George A. Kerr, Q.C., Minister

Everett Biggs, Deputy Minister

POSITION STATEMENT

ON

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POSITION STATEMENT

ON

WATER MANAGEMENT TECHNIQUES

INTRODUCTION

The employment of lake restoration techniques in general is a relatively youthful field of endeavour. There are many difficulties associated with remedial efforts. Lakes are complicated ecosystems and the ability to predict the response of lake systems to various treatments is as yet limited. Moreover, each lake has its own "unique personality" which frustrates attempts to transfer results from one lake to another that appears to have similar problems. The economics of lake restoration can also affect the choice of treatment alternatives, but this constraint may exist only because requisite equipment and/or experience is lacking.

APPROACH

The Environmental Protection Agency (1973) states that the approach to the rehabilitation of degraded lakes is two-fold: (1) by restricting the input of undesirable materials and (2) by providing in-lake treatment for the removal or inactivation of undesirable materials. Obviously, the only means of maintaining the quality of a lake once desired conditions are achieved, is by rigidly restricting the input of undesirable materials. In some lakes reducing or eliminating the primary sources of waste loading is the only restorative measure needed to achieve the desired level of improvements in the quality of the lake. However, in many lakes, particularly in hypereutrophic lakes with slow flushing rates, in-lake treatment schemes may also be required before significant improvements will be realized. In-lake treatment alone without controlling pollutional inflows cannot be termed a restorative measure as only the symptoms or products of eutrophication and pollution are treated and no permanent improvements in quality are achieved. In any lake restoration program, controlling the input of undesirable materials is the initial step towards permanent lake rehabilitation; all other remedial measures are supplementary to this action.

Dunst et al (1974) in their publication "Survey of Lake Rehabilitation Techniques and Experiences" stated that "curbing excessive nutrient and sediment inputs is the most effective and desirable long-term solution to the problems of lake degradation, but the time-span required to implement input control measures reinforced by the public's demand for "immediate" results, has stimulated the development of several schemes designed to limit the availability of nutrients already present in the lake ecosystem. In-lake

nutrient control techniques can accelerate the recovery of a lake from excessive fertilization and although they are undoubtedly most effective when preceded by a reduction in external loading, used alone they can also provide relatively rapid by usually only temporary relief from the effects of overfertilization".

GUIDELINES

Ministry of the Environment personnel have been involved in the development and study of lake restoration techniques over the past few years. Concomitant with the development of these techniques has been a growing awareness and interest of private individuals and groups in these techniques and their application to their specific water quality problems.

Although there are no guidelines, or criteria as yet on the application of these techniques to specific water quality problems it would behoove the Ministry to develop these guidelines at this propitious point in time in view of the ever increasing interest of the public into their utilization.

In view of the aforementioned the following considerations could be used as a basis for the development of guidelines for lake restoration techniques.

1.) A thorough assessment of the problem should be made and should include considerations of physical, chemical and biological characteristics of the lake. Some of these factors are:

    1. extent and magnitude of lake degradation and its effect on lake "usability",

    2. relative contributions of nutrient or contaminant sources including development of nutrient budgets,

    3. consideration of factors such as residence time, flushing rates, lake morphometry and wind effects,

    4. a thorough assessment of the interrelationships of physical, chemical and biological parameters.

2.) The results of the aforementioned considerations will facilitate the selection of a remedial technique or a combination of remedial techniques to be employed for water quality enhancement. Here again, several considerations are involved in the selection and utilization of lake restoration techniques;

    1. the possible deleterious affects of the treatment may outweigh the benefits,

2. the utilization of the technique must be worthwhile from a cost-benefit point of view

3. like most remedial techniques the enhancement in water quality may be temporal in nature. Consideration must be given to repetitive treatments in order to maintain improvements in water quality and usability.

4. the state-of-the-art on the refinement of the restoration technique may inflict limitations on the degree of success.

5. limitations may also be inflicted simply on the basis of economic constraints. The selection of the remedial technique as well as the scope of same will of necessity, be restricted by budgetary allotments.

In summation, a vast assortment of permutations and combinations of the aforementioned considerations as well as others must be assessed prior to the successful implementation of water quality remedial measures.

Given the present day state-of-the-art for a wide variety of lake restoration techniques more specific guidelines could be developed for particular techniques.

STUDIES

The remainder of this report is comprised of a brief survey of lake restoration techniques extracted from two state-of-the-art publications on the subject. Some additional Canadian studies have been added and/or updated through conversations and submissions from MOE personnel.

It should be noted that inclusions of personal communications in the references to most of these studies were submitted to the authors of the two state-of-the-art publications and not to the author of this position statement.

ARTIFICIALLY INDUCED DESTRATIFICATION AND HYPOLIMNETIC AERATION

DEFINITION

The terms artificially induced destratification and total aeration are frequently used interchangeably and refer to the technique of increasing the dissolved oxygen content of the bottom waters of lakes by eliminating thermal stratification and homogenizing the entire water volume (Smith et al, 1975).

In contrast to artificial destratification the process of hypolimnetic aeration does not disrupt the thermal stratification of a lake.

TECHNIQUE

Destratification is usually accomplished by lifting cold hypolimnetic water to the lake surface where it mixes with the warmer epilimnetic water and absorbs oxygen before sinking back to a new equilibrium depth. The entire lake can be circulated and aerated from a single site and it will eventually become almost isothermal.

The energy required to lift the denser bottom water can be supplied by either mechanical water pumps or compressed air released at the lake bottom. With either method atmospheric oxygen transfer at the lake surface and photosynthetic oxygen production play an important role in the aeration process.

For hypolimnetic aeration the aerator consists of a large diameter pipe which extends from the lake bottom to above the water surface. Water inlet ports are located near the bottom of the pipe and outlet ports are located below the metalimnion. The top of the pipe is open to the atmosphere. Air is released through a diffuser near the bottom of the pipe. As air rises in the pipe, water is drawn in through the bottom ports. Oxygen diffusion occurs as the water rises to the surface with the air bubbles. At the top of the pipe the air escapes into the atmosphere. The water sinks to the outlet port where it flows back into the hypolimnion. After the establishment of a hydraulic head in the pipe, water flows directly from the inlet to the outlet ports without rising to the surface.

Hypolimnetic water, therefore, is aerated but not significantly heated or mixed with epilimnion or metalimnion water. Thus, the dissolved oxygen level of the bottom waters is increased, but the integrity of the thermal strata is maintained with the warm water of the epilimnion overlying the cold water of the hypolimnion.

The benefits of artificial destratification and hypolimnetic aeration are most pronounced on eutrophic lakes which undergo oxygen depletion in the hypolimnion in contrast to oligotrophic lakes which never become oxygen deficient. The changes in water quality which are induced by these techniques include the following:

1. Due to the increased oxygen levels in the hypolimnion, there is a reduction in the anaerobic release of nutrients from bottom sediments. (Fast, 1971). This results in a general decrease in the productivity of the body of water.

   Also, due to higher hypolimnetic oxygen levels, oxidation of reduced organic and inorganic materials occurs in the water (Bernhardt, 1967). This is particularly important when the lake serves as a raw water supply. In such cases the need for specialized water treatment processes to remove taste and odour carrying materials such as iron and manganese is obviated.

2. The range of benthic populations is extended into areas which were once anaerobic (Fast, 1971). An increase in the number of fish and a shift to more favourable species could result due to the greater availability of food organisms (Fast, 1970 and 1971).

3. Favourable changes in algal populations occur with a decrease in undesirable blue-green species and an increase in green algae species (Symons et al, 1970). This is a result of the continued movement of the algae from the aphotic to the euphotic zones (Wirth and Dunst, 1967), the lowering of water temperature of the epilimnion, and the modification of the nutrient availability. The decrease in blue-green algae could result in a reduction in raw water taste and odour problems. There also appears to be a reduction in actinomycete population which could improve water taste (Symons, 1971).

4. Artificial destratification increases the heat budget of a lake by inducing complete circulation (Fast, 1971). An increased rate of productivity results. This is of particular importance in oligotrophic bodies of water.

5. Artificial destratification reduces evaporation rates by slightly reducing surface temperatures during the summer (Fast, 1968). In areas such as the southwest United States where water is in short supply and is expensive, significant savings can be achieved by reducing the rate of evaporation.

6. Artificial destratification often results in increased water clarity (Fast, 1971). This appears to be associated with reduced algal populations.

7. Winter fish kills may be prevented by artificial destratification due to the maintenance of high oxygen levels under ice (Lackey, 1972).

DISADVANTAGES

1. The increased heat budget produced by artificial destratification may be deleterious to cold water fishes, particularly in shallow lakes in which the temperature is increased excessively at all depths (Fast, 1968). Also, warmer lake waters may reduce a lake's usefulness as a source of cooling water for industry and, if the lake is a public water supply, the attractiveness of drinking water derived from the destratified lake (Bernhardt, 1967).

2. Both artificial destratification and hypolimnetic aeration may increase water turbidity due to the resuspension of bottom sediments (Symons, 1971). This is often a temporary problem, however, and may be resolved by continued mixing or a change in the location of the aerators.

3. In most investigations these methods have produced a reduction in blue-green algae populations with a subsequent increase in green algae such that total productivity remains about the same (Wirth and Dunst, 1967). In other instances there has been no observable affect on blue-green algae populations with the result that problems associated with these organisms have remained (Bernhardt et al, 1967).

4. If oxygenation is insufficient to increase the hypolimnetic oxygen concentrations rapidly enough during destratification, fish kills may occur (Leach, 1968).

5. The artificial destratification procedure may induce foaming, an aesthetically undesirable phenomenon (Wirth and Dunst, 1967).

6. The oxygen demand of resuspended anaerobic mud may result in a decrease in oxygen concentrations to the extent that fish kills occur (Bernhardt, 1967). This is particularly true of small, very eutrophic lakes.

CANADIAN STUDIES

LAKE NAME: Buchanan Lake
LOCATION: Dorset, Ontario
SURFACE AREA: 8.9 ha
MAXIMUM DEPTH: 13 m

PROBLEM: Hypolimnetic oxygen deficiency and epilimnion temperatures during the summer. Poor salmonid fishery despite extensive stocking.

RESTORATION OBJECTIVE: To maintain oxygen in the hypolimnion during the summer.

RESTORATION METHODOLOGY: An artificial aeration system was installed in order to mix the lake and maintain oxygen at all depths. A compressor supplied air at 4.7 l/sec to a diffuser placed in the deepest part of the lake. Capital cost was about $1,000 U.S.A. and operating costs were about $1/day.

RESULTS: The compressor ran continuously for 10 weeks during the summer of 1971 and was used again in the 1971-72 winter. Water quality rapidly improved after startup; the concentration of dissolved oxygen increased and concentrations of hydrogen sulphide, ammonia nitrogen, total phosphorus and iron decreased greatly. However, algal standing crop increased by 500-600 %, and water clarity decreased by 50%. Zooplankton populations increased four-fold, but changes in bottom fauna and sediment chemistry were inconclusive, although aeration apparently reduced the amount of organic matter in the sediments. The system maintained an open area during the winter about 110 m in diameter. Salmonids stocked in May, 1972 grew well and the lake has become attractive to anglers.

REFERENCE: Brown et al (1971), Brydges (pers. comm.).

LAKE NAME: Thompson Lake
LOCATION: Toronto, Ontario
SURFACE AREA: 4 ha
MAXIMUM DEPTH: 26 m

PROBLEM: Highly enriched due to intensive agricultural practices within the basin. In the summer the anaerobic hypolimnion extends to within 3 m of the lake's surface resulting in a limited fish habitat.

RESTORATION OBJECTIVE: To maintain oxygen in the lake at all depths in order to develop a salmonid fishery.

RESTORATION METHODOLOGY: An air diffuser was placed on the lake bottom at the 21 m depth to destratify the lake. Air was supplied with a compressor rated at 4.7 l/sec. Capital cost of the aeration system was $800 USA.

RESULTS: The system was started on 22 November, 1972. Water chemistry and algal response are being monitored, but results are not available.

REFERENCES: Brydges (pers. comm.)

LAKE NAME: Tory Lake
LOCATION: Nobleton, Ontario
SURFACE AREA: 1.38 ha
MAXIMUM DEPTH: 10 m

PROBLEM: Highly enriched due to agricultural practices within the basin. Anaerobic conditions exist below 3.0 m with attendant excessive concentrations of ammonia, hydrogen sulphide, carbon dioxide, iron, phosphorus and manganese.

RESTORATION OBJECTIVE: To maintain oxygen in the lake at all depths and induce sufficient improvements in water quality with the ultimate goal of establishing a salmonid fishery.

RESTORATION METHODOLOGY: An air diffuser was placed on the lake bottom at the 10 m depth to destratify the lake. Air was supplied with a compressor rated at 5.9 l/sec. Capital cost was about $2,000 Canadian and operating costs were about $1/day.

RESULTS: Upon application of artifically induced destratification significant improvements in the dissolved oxygen regime were evidenced with attendant reductions in hypolimnetic levels of ammonia, iron, manganese, BOD, turbidity, carbon dioxide, hydrogen sulphide and colour. Zooplankton extended their vertical habitat while benthic organisms showed marked increases in profundal zone populations accompanied by a dominance shift from chironomidae to Hirudinae.

The compressor was operated from July 21 to Oct. 7, 1975 and from April 14 to the present time (November 26, 1976). An attempted stocking of 300 rainbow trout (*Salmo gairdneri*) in May of 1976, presumably failed due to persistent depression of the dissolved oxygen regime. In-situ bioassay results in the fall of 1976, with an improved oxygen regime indicated a 100% survival of *Salmo gairdneri*. It appeared as if destratification had

induced sufficient improvements in water quality so as to allow for survival of a fish population. Another attempt at stocking will be conducted in the spring of 1977.

REFERENCES: Ellis (unpublished M.Sc. thesis)

LAKE NAME: Heart Lake
LOCATION: Brampton, Ontario
SURFACE AREA: 14.3 ha
MAXIMUM DEPTH: 10 m

PROBLEM: Oxygen depleted hypolimnion and blue-green algal blooms over the summer months.

RESTORATION OBJECTIVE: To maintain oxygen in bottom waters and regulate algal composition and biomass over the summer. Both of these objectives would in turn enhance the fisheries potential and recreational value of the lake.

RESTORATION METHODOLOGY: An aeration system was installed to completely mix the lake and extend the O_2 distribution down to the lakes' bottom. A shore-based electric compressor with a rated capacity of 12.2 c.f.m. was installed with a diffuser line leading to the deepest portion of the lake.

RESULTS: The compressor was installed during midsummer, 1975. There were immediate water quality improvements upon destratification: the disappearance of noxious gases (H_2S, NH_3, CO_2) via oxidation and/or a venting off from the lakes surface, a reduction in soluble Fe concentrations and increased O_2 in the bottom waters. This did not prevent, however, blue-green algal activity as observed by a quick succession of blooms over the remainder of the summer.

Immediately after ice-breakup in 1976, the compressor was started up and placed on a 12-hour on-and-off cycle in order to curtail machinery fatique and reduce the lake's summer heat income. For the first couple of months, aeration appeared to meet up to expectations. Following this there was a gradual decrease in O_2 value above the sediments. Mean total P values started to increase, along with other chemcial parameters until chemical concentrations were almost double those in 1975.

In the first week of July the compressor was set on continuous operation. This action did not avert the following events, namely the build-up of a massive bloom of Ceratium which upon collapsing in early August, caused deoxgyenation of the entire water column and an unprecedented fish kill in the lake. Research is continuing.

REFERENCES: Kennedy (pers. comm.), Nicholls and Kennedy (1976, unpublished data).

LAKE NAME: Hamilton Harbour
LOCATION: Hamilton, Ontario
SURFACE AREA: 2,150 ha
MAXIMUM DEPTH: 21 m

PROBLEM: Hypolimnetic anoxia and possible toxicity problems.

RESTORATION OBJECTIVE: To induce improvements in the dissolved oxygen regime and general water quality as well as the waste assimilative capacity of the harbour.

RESTORATION METHODOLOGY: Four diffuser lines were used to induce artificial mixing in Hamilton Harbour. The aerator lines were placed 61 m (200 feet) apart extending from the west wall of Stelco docks. Each line consisted of 5.08 cm (2 inches) polyethylene tubing (80 p.s.i. working pressure). Three of the lines consisted of a 191 m (625 feet) delivery section attached to a 305 m (1,000 feet) perforated line. The fourth line consisted of a similar delivery line with a 122 m (400 feet) perforated line. A 137 m (450 feet) steel header pipe connected the lines to a 0.28 m3 sec^{-1} (600 cfm) compressor which was used to supply the aerator lines.

An intensive survey of primary nutrients, heavy metals, mineral content, phytoplankton abundance and production and bacterial populations was performed. Relative abundance of zooplankton and fish populations was determined.

RESULTS: During the limited period of mixing (July-August, 1975) dissolved oxygen increased from 0 mg/l to 2 mg/l throughout the lower water column. There were no significant changes in heavy metals and mineral contents, but total phosphorus concentrations became more homogeneously distributed with depth, decreasing surface concentrations. Phytoplankton production and standing crop increased and bacterial populations declined. Zooplankton increased their habitat but fish, however, because of the limited period of mixing did not respond. It was apparent that artificial mixing increased the waste assimilation potential of the harbour.

REFERENCES: Haffner (pers. comm.), Haffner (1976).

LAKE NAME: Corbett Lake
LOCATION: British Columbia
SURFACE AREA: 24.2 ha
MAXIMUM DEPTH: 19.5 m

PROBLEM: Inefficient autumnal overturn; low oxygen content prior to ice cover. Oxygen depletion during the winter resulting in salmonid mortality in 6 out of 10 years prior to 1962.

RESTORATION OBJECTIVE: To increase the dissolved oxygen levels during autumnal overturn.

RESTORATION METHODOLOGY: An aeration/circulation system was installed in late fall, 1962. It consisted of a 750 l/sec air compressor connected to 726 m of perforated tubing, placed in a loop in the deepest part of the lake.

The system was intermittently operated during October and November, 1962 and again in 1963. The rental cost of the compressor was $325 U.S.A./month, and the tubing cost $400. In 1964 the line-release system was replaced with a simple air diffuser. Air was supplied with a 17 l/sec compressor. Initially the diffuser operated at the base of a 13 m long, 0.6 m diameter vertical tube which contained the rising bubbles, but the tube was not used in 1965 or in subsequent years. Total construction costs for the diffuser system were $774, excluding labour and design, and monthly operating costs were $135.

RESULTS: Prior to circulation in 1962, the lake was stratified at a depth of 10 m. At the end of the circulation period and just prior to freeze-up. Using either system the mean dissolved oxygen content of the lake was increased sufficiently to prevent the development of critical levels during winter, although the rate of demand was comparable to previous years.

REFERENCE: Halsey (pers. comm.), Halsey (1968), Halsey and Galbraith (1971).

AMERICAN STUDIES

LAKE NAME: Cox Hollow Lake
LOCATION: Iowa Co., Wisconsin
SURFACE AREA: 39 ha
MAXIMUM DEPTH: 8.8 m

PROBLEM: Highly eutrophic conditions; summer hypolimnetic oxygen depletion; nuisance algal growth; and high surface water temperatures. Poor fish growth and reproduction; and sharply declining sport fishery.

RESTORATION OBJECTIVE: To improve the dissolved oxygen levels during both summer and winter. To limit algal abundance.

RESTORATION METHODOLOGY: In July, 1966, six 3.6 m long "Aero-Hydraulic Guns" were installed in the deepest area in order to destratify the lake and oxygenate the bottom water. Air was supplied to the guns by two electrically-powered compressors, each rated at 34 l/sec. The guns transferred about 2400 l/sec. of water from the lake bottom to the surface. In 1967 the guns were replaced with three 1.5 m long "Helixors", which have been in operation to the present.

RESULTS: Both systems were successful in eliminating thermal and chemical stratification although minor gradients sometimes developed. Total phosphorus, Kjeldahl nitrogen, iron, and manganese concentrations decreased, but nitrate and nitrite concentrations increased during aeration. Benthic macroinvertebrates quickly became established in the profundal zones, but fish populations did not exhibit a substantial response, despite increased habitat and available food. Algal problems were not eliminated, but the blooms decreased in severity. Operation of the aeration system in the winter maintained dissolved oxygen levels well above the critical levels which had existed in previous years.

REFERENCES: Brezonik et al (1969), Wirth and Dunst (1967), (Wirth et al (1970).

LAKE NAME: El Capitan Reservoir
LOCATION: San Diego Co., California
SURFACE AREA: 17 km^2
MAXIMUM DEPTH: 62 m (full pool)

PROBLEM: Hypolimnetic oxygen depletion with a concomittant increase in anaerobic decomposition products and the exclusion of fish and other organisms from the profundal zone.

RESTORATION OBJECTIVE: To increase the dissolved oxygen concentration in the bottom waters during the summer in order to improve the water quality and enlarge the fish habitat.

RESTORATION METHODOLOGY: The destratification system consisted of a 31 m length of perforated tubing in the deepest part of the reservoir connected to an electric air compressor rated at 101 l/sec, 8.8 kg/cm^2. The capital and installation costs of the system were $6,010 U.S.A. Amortization of this cost over a 10-year period, plus power and maintenance costs, gave an annual cost of about $3,000.

RESULTS: Complete destratification was achieved during the summers of 1965 and 1966. During destratification, the temperature of the entire lake increased to approximately the same level as the epilimnetic temperatures during normal stratification. Dissolved oxygen was distributed to all depths but the surface concentrations were lower due to accelerated oxygen uptake. Aeration greatly decreased the iron, manganese, and hydrogen sulphide concentrations in the deeper waters without a substantial increase in the surface waters. Total phosphate concentrations and conductivity were also reduced. Destratification distributed zooplankton throughout the lake; however, they concentrated near the aerator and were subject to heavy predation by fish. Benthic organisms rapidly invaded the profundal zone during the period of destratification, and the total numbers in the lake dramatically increased. The increase in food organisms and habitat was probably beneficial to fish population but detailed studies were not conducted.

REFERENCE: Fast (1968, 1971b), Inland Fisheries Branch (1970).

LAKE NAME: Hemlock Lake
LOCATION: Cheboygan Co., Michigan
SURFACE AREA: 1.8 ha
MAXIMUM DEPTH: 18.6 m

PROBLEM: Hypolimnetic oxygen depletion; phosphorus regeneration from sediments.

RESTORATION OBJECTIVE: To maintain oxidizing conditions in the sediments and the overlying waters. To study the effects of hypolimnetic aeration on sediment nutrient release and the biota.

RESTORATION METHODOLOGY: The equipment was designed to aerate the hypolimnion without disrupting the lake's thermal stratification. Air was introduced through a diffuser at the base of a 1.38 m diameter pipe which extended from the lake's surface to a depth of 15.5 m. A second tube 12.3 m in length and 1.85 m in diameter, was placed concentrically around the smaller tube and extended 3.1 m above the lake surface. Water was airlifted up the inner tube and returned to the hypolimnion through the annular space. Air was supplied at a rate of 62 l/sec during June-July, 1970; 47 l/sec during July-September, 1970; and 24 l/sec. during a 48 hr period in January, 1971.

RESULTS: Within nine days the hypolimnetic oxygen levels increased from zero to 8 mg/l. During operation of the system there also was an increase in pH and a decrease in carbon dioxide, total alkalinity, and conductivity in the hypolimnion. Due to leaks in the system and heat transfer through the pipe walls the bottom water temperature increased gradually. Intense algal blooms occurred immediately after the onset of aeration and in August; production and standing crops were unusually low during the intervening period. Zooplankton and zoobenthos populations increased during aeration, primarily due to the enlarged livable zone. Although the system was not as successful as anticipated, the difficulties were thought due to improper design of the equipment. In the winter of 1970-71, dissolved oxygen concentrations were much higher than during the previous winter, presumably due to increased decomposition of organic material during the summer. A short test of the aerator succeeded in increasing the oxygen levels.

REFERENCE: Ball (pers. comm.), Fast (1971a, 1973).

DILUTION/FLUSHING

DEFINITION

The water quality of some lakes can be improved by diluting or replacing the existing water with a water of higher quality. Dilution flushing has primarily been attempted to alleviate excessive algal growths and associated problems by reducing nutrient levels within a lake.

TECHNIQUE

Lake restoration projects have attempted nutrient dilution by two procedures (1) pumping water out of the lake, thus permitting the increased inflow of nutrient poor ground water (refer to Snake Lake project under Drawdown section) and (2) routing additional quantities of nutrient-poor surface waters into the lake.

FACTORS TO BE CONSIDERED PRIOR TO IMPLEMENTATION

1. Welch et al (1972) established that the maximum biomass of problem algal species can be reduced in direct proportion to the amount of dilution water added, providing dilution is lowering the concentration of the limiting nutrient. Therefore, the dilution water must either contain lower concentrations (below levels necessary for nuisance growths) of the in-lake limiting nutrient or lack some other constituent that will control algal biomass by becoming the new in-lake limiting nutrient.

2. Bottom deposits may play an important role in determining nutrient levels within a lake and leaching can negate the potential effects of the influx of nutrient-poor water. This is an important consideration for lakes with extensive shallow water areas and in situations where dilution/flushing is not continuous. For instance, due to leaching, the Snake Lake project had only partial success; laboratory studies suggested that continued pumping would have eventually depleted the nutrient content of the sediments (Born et al, 1973).

3. Lake morphometry and hydrodynamics need to be investigated. A dilution/flushing study at Chain Lake, Canada was labeled a failure at least partly due to poor placement of the inflow (Northcote, pers. comm.).

   Although economic considerations and logistics may severely limit the number of applications, the technique can and has been used effectively. Certain in-lake phenomena have been identified as important and thorough pre-treatment investigations should increase the degree of success in future dilution/flushing programs.

CANADIAN STUDIES

LAKE NAME: Buffalo Pound Lake
LOCATION: Moose Jaw, Saskatchewan
SURFACE AREA: 29.2 km^2
MAXIMUM DEPTH: 5.6 m

PROBLEM: Blue-green algal blooms and deoxygenation under ice-cover. Eutrophy caused by agricultural drainage including feedlots; probably cottage owner septic tanks influential.

RESTORATION OBJECTIVE: To limit blue-green algal growth and improve water quality (used as source of water for about 100,000 people).

RESTORATION METHODOLOGY: The input of water from high quality, oligotrophic Lake Diefenbaker was accomplished via canal on an intermittent basis with the emphasis on winter flow. Inflow began in July, 1967 and has continued at highly variable discharge to the present.

RESULTS: The most marked change in water chemistry occurred during the first year; however, a gradual improvement continued in subsequent years. By 1972 total dissolved solids and major ion concentrations were halved; orthophosphate levels were reduced by 90%; nitrate nitrogen was down 80% and ammonia nitrogen decreased by 60%. Blue-green algal populations (mostly Aphanizomenon) decreased more slowly and it was not until 1971 that they remained at sub-nuisance densities. The algal reduction has been accompanied by major increases in Potamogeton pectinatus in the shallows.

REFERENCES: Hammer (pers. comm.), Hammer, (1972).

LAKE NAME: Chain Lake
LOCATION: Princeton, British Columbia
SURFACE AREA: 12.4 ha
MAXIMUM DEPTH: 5.5 m; 7.9 (1970)

PROBLEM: Heavy summer algal blooms and high water turbidity caused reduced recreational use.

RESTORATION OBJECTIVE: To divert low nutrient water on an experimental basis in order to reduce algal blooms and prevent severe water discolouration during the summer recreational period.

RESTORATION METHODOLOGY: Low nutrient water was diverted from a nearby creek system 2.5 - 7.5 x $10^5 m^3$ annually to a lake volume of 2.7 x $10^6 m^3$. Cost for fluming ditch, maintenance, and evaluation approached $30,000 U.S.A. for the period 1965-72.

RESULTS: No significant effect on the physical, chemical, or biological conditions in the lake could be assigned to the diversion project, probably because the water volume available for diversion was too small and its entry into the lake was poorly located.

REFERNCES: Ennis (1972), Northcote (pers. comm.), Northcote (1967), Taylor (pers. comm.), Taylor (1971, 1972).

AMERICAN STUDIES

LAKE NAME: Green Lake
LOCATION: Seattle, Washington
SURFACE AREA: 1 km^2
MAXIMUM DEPTH: 8.8 m

PROBLEM: Nuisance blue-green algal blooms in the summer; dense emergent vegetation problem around the shoreline; 0.3 to 1.5 m layer of easily disturbed organic sediments.

RESTORATION OBJECTIVE: To decrease the summer standing crop of blue-green algae and to deepen the shoreline in order to reduce the macrophyte density.

RESTORATION METHODOLOGY: In the early 1960's the lake was deepened to a limited extent by vacuum dredging. A total of about $10^6 m^3$ of sediments were removed at a cost of $168,000 U.S.A. ($0.17/m^3). Starting in 1962 low-nutrient city water was added to dilute the P concentration and therefore reduce the algal population. The amount of water was determined by availability; there was much fluctuation with time, but the long-term average was 1% of the lake volume/day. The capital cost was $400,000-500,000 U.S.A. and operating costs were negligible.

RESULTS: Measurements in 1965-67 were compared with 1959. The inflow mixed with the lake water. The concentrations in 1959 vs. 1967 were 0.234 mg/l vs. 0.064 mg/l for total P; 0.019 mg/l vs. 0.018 mg/l for soluble P; and 0.073 mg/l vs. 0.022 mg/l for nitrate nitrogen. The concentration of total P was still higher in the lakewater than in the dilution water in 1967. Blue-green algal standing

crops were suppressed; there was a shift in the dominant algal species (Aphanizomenon was eliminated); and transparency increased greatly.

REFERENCES: Engineering News-Record (1962), Millenbach (pers. comm.), Oglesby (pers. comm.), Oglesby (1968a and b, 1969), Oglesby and Edmondson (1966), Shepherd (1968), Sylvester (pers. comm.), Sylvester and Anderson (1960, 1964).

DRAWDOWN

DEFINITION

Sediment exposure and dessication via lake drawdown is achieved by artificially manipulating water levels in a lake or impoundment for the purposes of inducing stabilization of bottom sediments and retarding nutrient release.

TECHNIQUE

Drawdown is achieved by the installation and operation of high capacity irrigation pumps for the purposes of lowering water levels and subsequently exposing large areas of sediment. In man-made lakes and reservoirs this is achieved by manipulations of flood control gates or dams.

ADVANTAGES

1. By reducing the sediment oxygen demand and increasing the oxidation state of the surface layer, drawdown may retard the subsequent movement of phosphorus from the sediments.

2. Sediment exposure can also curb sediment nutrient release by physically stabilizing the upper flocculent zone of the sediments which plays an important role in the exchange reactions and mixing of the sediments with the overlying water.

3. Some studies have shown that sediment exposure and dessication can increase the lake depth.

4. This technique also allows for an opportunity to undertake other enhancement measures such as the removal of bottom stumps and logs, sediment removal and sediment sealing.

5. Marked improvements in water quality resulted from drawdown with reductions in algal crop and subsequent establishment of rooted aquatic plants. These plant establishments resulted in improved game fish habitat.

DISADVANTAGES

1. Agricultural studies of organic soils suggested that lake sediment dessication will accelerate microbial conversion of the organic forms of nutrients to inorganic forms (Davis and Lucas, 1958).

2. Drawdown and dry fallowing with subsequent reflooding are widely used to increase the fertility of fish culture ponds (Neess, 1946; Sniesko, 1941). This may or may not be a disadvantage depending upon the objectives of the work.

3. Keeney and Bryans (1972) concluded that sediment drying resulted in a physical breakdown of organic material for microbial attachment and lead to a more rapid mineralization of organic nitrogen upon rewetting.

AMERICAN STUDIES

LAKE NAME: Jyme Lake
LOCATION: Oneida Co., Wisconsin
SURFACE AREA: 4,000 m^2
MAXIMUM DEPTH: 36 m

PROBLEM: Accumulation of low density, organic-rich sediments (6 m thick)

RESTORATION OBJECTIVE: To determine the effectiveness of drawdown and sediment drying as a technique for consolidating the sediments in a natural lake.

RESTORATION METHODOLOGY: A high capacity irrigation pump was used to remove the lake water to a nearby marsh. The water level in the lake was lowered at about 15 cm/hr. The inflow of low density sediments from beneath a floating bog adjacent to the lake forced the termination of pumping prior to complete drawdown.

RESULTS: Although laboratory testing indicated that the sediments were highly susceptible to consolidations valid in lake data were not obtained because of sediment flow and incomplete drawdown. The low strength characteristics of the upper layers of the sediments permitted movement as the lake level was lowered. Measurable consolidation did however occur in the stable portions of the adjacent bog at distances up to 30 m from the lake. Extensive slumping also occurred in the bog during lake drawdown, but most evidence of slumping disappeared as the lake refilled.

REFERENCES: Smith et al (1972)

LAKE NAME: Marion Millpond
LOCATION: Marion, Waupaca Co., Wisconsin
SURFACE AREA: 43.8 ha
MAXIMUM DEPTH: 3.7 m

PROBLEM: Excessive growth of macrophytes and filamentous algae. Slow-growing fish population.

RESTORATION OBJECTIVE: To restore the scenic and recreational potential of the lake.

RESTORATION METHODOLOGY: Plastic sheeting was placed on the lake bottom with a sand or gravel blanket on top. The cost was approximately $494 U.S.A./ha. Some dredging was also conducted in selected areas.

RESULTS: Good control of macrophytes resulted for two growing seasons after treatment. Chara was rapidly invading some areas and the permanence of treatment was questionable.

REFERENCES: Born et al (1973b)

LAKE NAME: Snake Lake
LOCATION: Vilas Co., Wisconsin
SURFACE AREA: 5 ha
MAXIMUM DEPTH: 5.5 m

PROBLEM: DO depletions, nuisance growths of vegetation and recurring winterkills.

RESTORATION OBJECTIVE: To alleviate the conditions.

RESTORATION METHODOLOGY: Nutrient-rich waters were pumped from the lake to a nearby land disposal area, permitting dilution of the remaining waters with low-nutrient influent ground waters. Pumping removed about two-thirds volume in October, 1969 and three volumes during July-August, 1970. In 1972, aluminum (III) was applied to the lake for phosphorus inactivation/precipitation and bottom sealing.

RESULTS: During pumping the lake level temporarily declined about 3.4 m, this resulted in a beneficial deepening of the littoral zone due to dewatering and sediment consolidation. Severe DO depletion continued during the two winters following pumping. The soluble P concentration was significantly diluted and has remained so for two years (total P levels are still relatively high). Nitrogen, chloride, conductance, and colour levels were temporarily reduced, but returned to pre-pumping concentrations within one year.

Nuisance blooms of Lemna (duckweed) were eliminated. The study demonstrated that rapid pumping of some small lakes is technically feasible; and lab experimentation indicated that this renewal technique will be more effective in lakes with less nutrient-rich sediments. Prior to the aluminum treatment, total P concentrations were 0.2 to 0.5 mg/l. During the subsequent year the level ranged from 0.02 to 0.07 mg/l. Dissolved oxygen conditions during the winter following treatment were noticeably improved. Studies are continuing.

REFERENCES: Born et al (1973a), Peterson (pers. comm.), Smith (undated).

LAKE NAME: Tohopekaliga
LOCATION: Osceola Co., Florida
SURFACE AREA: 92 km^2
MAXIMUM DEPTH: 4.6 m (full pool)

PROBLEM: Accumulation of flocculent organic sediments. Degradation of fish habitat. Nuisance algal blooms. Lack of macrophytes. Encroachment by agricultural and urban development. These problems were a direct result of water level stabilization in 1964; the historic natural range of water level fluctuation was reduced by about 55%.

RESTORATION OBJECTIVE: To improve the conditions by consolidating and stabilizing the bottom sediments. To evaluate the effects of drawdown.

RESTORATION METHODOLOGY: After preliminary studies and local community acceptance, the lake was artificially lowered during 1970-72. Water levels were dropped 0.9 m between March and June, 1970, remained stable until February, 1971; reached the maximum drawdown by June, 1971; and raised to near normal between August, 1971 and March, 1972. Draining was done by gravity and costs were therefore nominal. Approximately $200,000 USA was spent over a period of four years for monitoring the effects of dewatering on physical, chemical and biological parameters.

RESULTS: Compaction or loss (due to wind erosion or complete oxidation) of organic sediments ranged from 55 to 100%. The thickness of organic materials at 10 sampling stations varied from about 3 to 55 cm. prior to drawdown and from 0 to 10 cm. after drawdown. The sediments either disappeared completely or became compacted, peat-like material. In all areas the substrate became firm and solid and except in those areas which were not completely dried remained solid after refilling only slight expansion occurred. Although reduction in the concentrations of ammonia, organic nitrogen and volatile solids in the sediments were expected, error in laboratory procedures tended to obscure the results. An inconsistent reduction in ammonia content was noted. A 24 hr carbon dioxide evolution test carried out on the exposed sediments showed that the drying organic material was releasing considerable amounts of carbon dioxide due to microbial activities. Water quality monitoring before and during drawdown indicated that most dissolved constituents increased in concentration during drawdown.

During refilling, reductions occurred and concentrations approached pre-drawdown levels (total phosphorus was lower throughout the lake). Excessive algal production was not reduced by dewatering, although a greater species diversity was observed after refilling. Fish and invertebrate populations doubled in less than a year following drawdown.

REFERENCES: Holcomb (pers. comm.), Holcomb and Wegener (1971), Pride (pers. comm.), Wegener (pers. comm.), Wegener and Holcomb (1972).

DREDGING

DEFINITION

Dredging can be defined as a remedial technique used to physically remove sediment organic detritus for the purpose of inducing improvements in water quality and/or retarding the eutrophication process.

TECHNIQUE

Removal of organic sediments is achieved through the implementation of a wide variety of mechanical, hydraulic or pneumatic dredges.

ADVANTAGES

Decreased lake depth resulting from organic and inorganic sedimentation is one of the common consequences of lake aging. Lake dredging can have the following beneficial effects.

1. In shallow, unstratified lakes, the rate of sedimentary phosphorus release can be a major source of nutrients for aquatic growth. The removal of this sediment with dredging can remove a major source of nutrients.

2. Shallow lakes often contain extensive growths of rooted aquatic plants and are more prone to winterkill than deep lakes. Deepening, through dredging reduces the size of the littoral zone and provides additional water surface suitable for recreational use. Dredging also decreases the ratio of sediment surface to water volume and can create a sufficient volume of oxygenated water to prevent the onset of anaerobiosis during periods of ice cover.

3. Increasing the depth of water can eliminate fish winterkills.

DISADVANTAGES

1. The relatively high costs of dredging operations may make this technique prohibitively expensive on large lakes.

2. The dredging operation may release nutrients from the sediments, making them available for reinvolvement in the food web. The nutrient content of many sediments may remain high at considerable depths, making it impossible to reach a low nutrient level in the sediment.

3. The elimination of shallow zones which maintain large macrophyte beds, may result in a considerable increase in the algal populations. The nutrients formerly tied up in macrophyte biomass could become available for algal growth. The result may be the substitution of one problem for a second.

4. Turbidity resulting from the dredging process may persist for a considerable time during and following dredging.

5. Disposal of the dredged spoils economically is often impossible. Sediments may prove unsuitable for agricultural purposes and in such a case, could be used for land fill only.

6. Interstitial waters contained in sediments are frequently high in nutrients, consequently, disposal of the sediments must be in such a manner that leaching of nutrient waters back to the lake is prevented.

AMERICAN STUDIES

LAKE NAME: Herman Lake
LOCATION: Madison, South Dakota
SURFACE AREA: 5.3 km^2
MAXIMUM DEPTH: 3 m

PROBLEM: Sediment accumulation. Decreased water depth; occasional winterkills.

RESTORATION OBJECTIVE: To deepen part of the lake in order to provide a sufficient volume of oxygenated water for over winter fish survival.

RESTORATION METHODOLOGY: A 4 ha bay was deepened to an average depth of 3.5 m with a 25 cm hydraulic cutterhead dredge. About 54,000 m^3 of sediments were removed at a cost of \$0.25 U.S.A./m^3.

RESULTS: Dredging was recently completed, and results with respect to winterkill are not yet available. Water quality was carefully monitored during the dredging and there apparently was little effect. Based on background data and simultaneous monitoring in a downstream lake, the only water quality parameter that may have been affected by dredging was orthophosphate. Concentrations approximately doubled throughout the lake, however, no concentration gradient was detected towards the dredged area.

Turbidity created by the dredge was less than that which developed in the water during high winds.

REFERENCES: Broshier (pers. comm.), Broshier et al (1973), Johnson (pers. comm.).

LAKE NAME: Crystal Lake
LOCATION: Lake Crystal, Minnesota
SURFACE AREA: 1.6 km^2
MAXIMUM DEPTH: 4.5 m

PROBLEM: Excessive nutrient and sediment influx. Winter dissolved oxygen depletions; fishkills; and nuisance algal growth.

RESTORATION OBJECTIVE: To minimize the winterkills and to reduce algal production.

RESTORATION METHODOLOGY: A used dredge was purchased and outfitted at a cost of about $50,000 U.S.A. Operation began in 1970. Spoils are discharged to a diked-off area in a shallow bay contiguous to the lake. Annual cost of the operation is about $25,000.

RESULTS: The rate of sedimentation in nearly equal to the production of the dredge and there has been no noticeable improvement in lake water quality. Presumably deterioration has been arrested, however, and the spoils have been used for considerable economic value.

REFERENCES: Henney (pers. comm.).

SWEDISH STUDIES

LAKE NAME: Lake Trummen
LOCATION: Vaxjo, Sweden
SURFACE AREA: 70 ha
MAXIMUM DEPTH: 2 m

PROBLEM: Heavy growths of algae and macrophytes. Winter oxygen depletions and fishkills; low DO's at night during the summer. Upper 40-50 cm of sediments rich in nutrients. Recipient of sewage and industrial waste until 10 years ago; subsequent natural recovery was unsatisfactory.

RESTORATION OBJECTIVE: To remove the upper nutrient-rich sediments in order to improve the trophic status of the lake.

RESTORATION METHODOLOGY: Dredging operations began in 1970. The upper 50 cm of lake sediments were removed. During 1971 a cutter head was used to dredge weedy areas. Spoils were pumped to sedimentation ponds and the clarified return water was treated with aluminum sulphate to remove phosphorus.

RESULTS: Dredging of 600,000 m^3 of gytta (sediment) has increased the lake volume by 70%. The total phosphorus concentration of the lake water in the summer of 1971 was about 100 μg/l compared to values as high as 1,000 μg/l in 1968 and 1969. Changes in Kjeldahl nitrogen, alkalinity, and pH are probably attributable to aluminum sulphate treatment of the return waters. Dissolved oxygen concentrations remained well above critical levels during the winter of 1970-71, compared to total depletion in earlier years. In 1970-71 green algae replaced blue-green algae to a large extent, although phytoplankton production was still high in 1970. Recolonization by macrophytes is expected due to the declining phytoplankton turbidity. Improvements in water quality (e.g. transparency, nutrient content, and productivity) have continued through the summer of 1973.

REFERENCES: Andersson et al 1973, Bjork (pers. comm., 1972a and b), Bjork et al (1972), Gibson (1971).

Note: For further details of this study see; Bengtsson, L., S. Fleischer, G. Lindmark and W. Ripl, 1975. Lake Trummen restoration project. l. Water and sediment chemistry. Verh. Internat. Verein. Limnol. 19, 1081-1087, Cronberg G. and C. Gelin and K. Larsson, 1975. Lake Trummen restoration project. ll. Bacteria, phytoplankton and phytoplankton productivity. Verh. Internat. Verein. Limnol., 19, 1096-1106.

LAKE BOTTOM SEALING

DEFINITION

The application of a substance or material to lake sediments for the purpose of sealing off those sediments and thus disallowing or retarding nutrient exchange with the overlying water by physically retarding exchange or by increasing the capacity of surface sediments to hold nutrients.

TECHNIQUE

Many materials have been used as sediment sealants. These include; plastic sheeting, rubber liners, sand, fly ash, clays, hydrous metal oxides and gels.

ADVANTAGES

Covering of bottom sediments with sheeting material (plastic, rubber, etc.) or particulate material (clay, fly ash, etc.) can theoretically perform three functions in restoring eutrophic lakes:

1. it can prevent the exchange of nutrients from the sediments to the overlying water.

2. it can prevent or retard the establishment of rooted aquatic plants.

3. materials such as kaolinite and fly ash can remove phosphate from water and carry it to the bottom in a relatively insoluble form.

DISADVANTAGES

One problem encountered when covering sediments is the ballooning of sheeting, or rupturing the seal of particulate material, when gas is produced in the underlying sediments.

For particulate material, the small sizes which have relatively low effective specific gravity (i.e. clays, fly ash) appear to be best suited for sediment covering. Materials of larger size (sand and silts) tend to sink below flocculent sediments. Sands and silts, however can be effective in areas where the sediments are more consolidated.

AMERICAN STUDIES

LAKE NAME: Marion Millpond
LOCATION: Marion, Waupaca Co. Wisconsin
SURFACE AREA: 43.8 ha
MAXIMUM DEPTH: 3.7 m

PROBLEM: Excessive growth of macrophytes and filamentous algae. Slow-growing fish population.

RESTORATION OBJECTIVE: To restore the scenic and recreational potential of the lake.

RESTORATION METHODOLOGY: Plastic sheeting was placed on the lake bottom with a sand or gravel blanket on top. The cost was approximately $494 USA/ha. Some dredging was also conducted in select areas.

RESULTS: Good control of macrophytes resulted for two growing seasons after treatment. Chara was rapidly invading some areas and the permanence of treatment was questionable.

REFERENCES: Born et al (1973b)

LAKE NAME: Stone Lake
LOCATION: Cass Co., Michigan
SURFACE AREA: 61 ha
MAXIMUM DEPTH: 18.3 m

PROBLEM: Nuisance blue-green algal blooms; overabundance of macrophytes and high phosphate concentrations in the water and sediments. The high nutrient levels were caused by the influx of sewage plant effluent (secondary treatment) during 1939-65.

RESTORATION OBJECTIVE: To limit the algal and macrophyte growth by reducing the phosphorus concentration in the water and controlling the release of nutrients from the sediments.

RESTORATION METHODOLOGY: The inflow of treatment plant effluent was stopped in 1965. A proposed treatment for the summer of 1974 involves phosphate precipitation and settling by addition of fly ash and lime. Concurrently the bottom sediments will be sealed to stop the release of nutrients. The estimated treatment costs will be $2470 U.S.A./ha.

RESULTS: Laboratory and field testing have produced a successful application technique. Various chemical and biological studies are underway in two 0.4 ha ponds.

REFERENCES: Cratty (pers. comm.), Tenney (pers. comm.), Tenney and Echelberger, Jr. (1970), Tenney et al (1972), Verhoff et al (1971).

UNIVERSITY OF NOTRE DAME - FLY ASH STUDIES

The University of Notre Dame is evaluating fly ash to cover and prevent sediment nutrients from entering the overlying waters. This appears to have promise not only as a barrier between sediment and water but also as a material to remove phosphate from the lake during application.

The possible consequences resulting from the application of fly ash to lakes as a sediment covering agent should be thoroughly evaluated prior to application. Fly ash frequently contains numerous impurities including several heavy metals, phosphorus, boron, radioactive wastes and many others. The damage resulting from treatment with fly ash could conceivably affect any benefits.

Members of the Department of Civil Engineering are in the process of conducting in-situ fly ash experiments in Lake Charles near South Bend, Indiana in preparation for a full scale treatment. They intend to seal off the lake into control and treated portions by means of a fibreglass barrier and subsequently treat one portion of the lake with 1700 tons of fly ash to yield a sediment cover of approximately 5 cm.

NUTRIENT INACTIVATION/PRECIPITATION

DEFINITION

Nutrient inactivation can be defined as the adding of some type of material that will bind with, absorb, or otherwise immobilize necessary algal nutrients thus preventing them from being utilized by these organisms for their growth.

TECHNIQUE

A number of chemicals have been used for nutrient removal either in laboratory studies or in actual field applications. These include aluminum, iron, calcium, zirconium and lanthanum. Other materials being used or considered as coagulants or sorption agents include ion exchange resins, polyelectrolytes, aerobic lake mud, flyash, powdered cement and clay. By far aluminum has received the most attention in terms of actual field use.

The most common techniques for the application of nutrient inactivants is by dry chemical broadcasting and manifold injection. In the case of aluminum sulphate the chemical is mixed in slurried form and then injected into the water body. Slurried aluminum sulphate can be added to the epilimnion or injected into hypolimnetic waters.

The advantages of nutrient inactivation will become evident in the summary of field studies, however, there are some disadvantages to this technique.

DISADVANTAGES

1. The relatively high expense of treating a body of water.

2. Possible toxic effects on the biota by or through the introduction of an excess of the metal used as a precipitant.

3. Adverse biological effects from the formation of a floc. The material used may be non-toxic but the floc could conceivably suffocate aquatic organisms by interfering with their respiratory mechanisms.

4. In order to obtain maximum effectiveness, it may be necessary to either raise or lower the pH of the system which could have serious biological consequences.

5. The addition of certain salts, such as sulphates and chlorides, may increase the conductivity of the water to an unacceptable level. In the case of sulphate, if the hypolimnetic waters should become anaerobic after treatment, reduction of the sulphate would lead to the release of hydrogen sulphide.

6. Little information is available on the effective duration of the treatment. Wind actions, continued inflow of nutrients, bacteriological and benthic organism activity are a few of the phenomena which could possibly influence the longevity of treatment effects.

7. The time of application of the inactivant may be critical; it may be necessary to apply the material when the maximum nutrient content is present in the water.

CANADIAN STUDIES

LAKE NAME: Welland Canal
LOCATION: Ontario
SURFACE AREA:
MAXIMUM DEPTH:

PROBLEM: Possible deterioration of water quality in the Welland Canal after its closing. The existing canal will be replaced with a new one in 1973; nuisance algal blooms are anticipated after the canal closing.

RESTORATION OBJECTIVE: To develop procedures for protecting the water quality. To determine the efficiency and feasibility of alum treatment as compared to other control alternatives.

RESTORATION METHODOLOGY: These techniques were studied (1) treatment with aluminum sulphate at a dosage of 5 mg/l as Al, (2) maintenance of a four day hydraulic residence time, and (3) application of copper sulphate at a rate of 1 mg/l. Alum treatment cost about $290 U.S.A./ha. The tests were conducted in three separate basins of a previously used canal.

RESULTS: Algal productivity was limited by each of the techniques; alum treatment was more effective than the four day retention time. Copper sulphate reduced the productivity for 2-3 weeks only. Initially the alum reduced total phosphorus concentrations to 10 μg/l; in addition, turbidity decreased and water transparency increased. However, by the end of summer pre-treatment conditions again existed due to the shallowness of the basin and the influx of suspended materials in the runoff waters. More permanent results would be expected from treatment of the soon-to-be-closed canal because of the deeper basin. The investigation is continuing including analyses of various biological data.

REFERENCES: Shannon and Vachon (1973).

LAKE NAME: M.T.R.C.A. Pond
LOCATION: Bolton, Ontario
SURFACE AREA: $638 m^2$
MAXIMUM DEPTH: 2.7 m

PROBLEM: Deterioration of water quality characterized by high levels of phosphorus, ammonia with attendant low dissolved oxygen levels and water transparency.

RESTORATION OBJECTIVE: To assess the improvements in water quality induced by treatment with aluminum sulphate as well as the duration of treatment.

RESTORATION METHODOLOGY: A 6 mil polyethylene barrier was constructed in order to affect control and treated portions. Based on an alum dose of 250 µg/l as $Al_2(SO_4)_3 \cdot 14 H_2O$ a volume of 3.84×10^5 liters (volume of treated pond section) was treated with 211 lbs. of alum. Dry alum was mixed with pond water in a large plastic vat until a slurry had formed. This slurry was applied to the treated portion of the pond by "bucketing" the slurried alum into the prop wash of an outboard motor. The boat was run in transects parallel to the shoreline to insure uniform distribution of the alum slurry.

RESULTS: Alum treatment resulted in a 70% and 90% removal of total and dissolved reactive phosphorus respectively. In addition significant reductions in ammonia and organic nitrogen resulted. Treatment permanence was approximately three months in duration. Dissolved oxygen showed a sharp increase following treatment while pH and alkalinity showed temporary decreases. There was a relatively long-lasting complete reduction in the blue-green Chroococcus. Short-term improvements in water transparency were seen.

REFERENCES: Ellis (1975)

AMERICAN STUDIES

LAKE NAME: Horseshoe Lake
LOCATION: Manitowoc Co., Wisconsin
SURFACE AREA: 9 ha
MAXIMUM DEPTH: 17 m

PROBLEM: Nuisance blue-green algal blooms and winter fishkills. Eutrophic conditions apparently induced by agricultural wastes and the prior influx of dairy wastewaters.

RESTORATION OBJECTIVE: To limit planktonic algal growth and improve dissolved oxygen conditions by reducing the phosphorus concentration.

RESTORATION METHODOLOGY: Precipitation/sorption and settling of phosphorus was attempted in May, 1970. Slurried alum was applied at a rate of 10 mg of aluminum/l in the surface 0.6 m. The chemical costs were $74 U.S.A./ha.

RESULTS: Treatment decreased the total phosphorus in the lake water. Concentrations of phosphorus were reduced for two years (period of study) after treatment. Of particular significance, the phosphorus concentrations in the hypolimnion were diminished and maintained at low levels. Although Chara became more abundant, nuisance planktonic algal blooms were eliminated. Dissolved oxygen concentrations in the hypolimnion were increased. No adverse ecological consequences were observed.

REFERENCES: Peterson et al (1973).

LAKE NAME: Cline's Pond
LOCATION: Polk Co., Oregon
SURFACE AREA: 0.4 ha
MAXIMUM DEPTH: 3.7 m

PROBLEM: Highly eutrophic; hypolimnetic oxygen depletion during the summer. Conditions result from nutrients contained in introduced fish food and in drainage waters from the surrounding farm land.

RESTORATION OBJECTIVE: To eliminate the excessive algal growth and to maintain an increased oxygen content throughout the summer through nutrient inactivation/ precipitation.

RESTORATION METHODOLOGY: The pond was treated in April, 1971. A floc of aluminum hydroxide was achieved using sodium aluminate at a rate of 10 mg Al/l of water. However, the aluminate was first neutralized to pH 7.0 with hydrochloric acid, because the water in the pond was very soft and unbuffered. The materials cost $500 U.S.A.

RESULTS: Treatment decreased the degree of eutrophy-Phosphorus (orthophosphate and total phosphorus), total Kjeldahl nitrogen, ammonia, silca, iron, manganese, phytoplankton, chlorophyll a and suspended solids were lowered. Transparency was greater, pH less variable and oxygen remained more constant, near 100% saturation. No salmonid kills were experienced

after treatment and fish were not affected by the treatment. A change was noted in algal species and tests utilizing the Algal Assay Procedure indicated a temporary reduction in the growth potential.

REFERENCES: Gahler (pers. comm.) Gahler et al (in prep.) Sanville (pers. comm.)

LAKE NAME: Dollar Lake
LOCATION: Portage County, Ohio
SURFACE AREA: 2.22 ha
MAXIMUM DEPTH: 7.5 m

PROBLEM: Eutrophic lake characterized by thermal stratification and intense blue-green algal blooms as a result of nutrient inputs from developed areas in the watershed.

RESTORATION OBJECTIVE: The objectives were to (1) evaluate the effectiveness of hypolimnetic application of alum in removing phosphorus, (2) evaluate the effectiveness of the floc in preventing post treatment release of phosphorus from anoxic sediments, (3) to evaluate the effect of fall and spring circulation on the floc, (4) to develop application methods and procedures and (5) assess environmental impact.

RESTORATION METHODOLOGY: The hypolimnion of the lake was treated with 9.2 tons dry or 18.4 tons of liquid (50%) aluminum sulphate. A light (10% of calculated maximum dose) treatment of the epilimnetic waters was conducted following hypolimnetic treatment.

The liquid alum was stored in a 700 cubic foot above-ground pool, and a gasoline pump was employed to pump the alum out to an anchored boat. An application barge, powered by a 20 h.p. outboard motor, carried a 300 gallon tank which was loaded from the anchored boat. A 50% mixture of alum and lakewater was pumped down hoses to a 5 metre long application manifold and hence into the hypolimnion.

RESULTS: Following treatment there was a substantial reduction in the total phosphorus content and phosphorus levels remained low in the subsequent weeks. Transparency increased from 0.75 metres before treatment to 3.85 metres in the first week following treatment. As a result of increased light penetration, photosynthetic activity of Oscillatoria mats on the sediment increased which resulted in a brief appearance of small mats of algae and detritus on the water surface, carried

by bubbles. Net community photosynthesis dropped by an order of magnitude in surface waters, but extended to a greater depth zone. Dissolved oxygen was less in the surface water but extended to previously anoxic zone. Treatment resulted in a substantial reduction in phytoplankton by entrapment and sedimentation. No mortality or stress to fish was observed. Zooplankton (Daphnia, Cyclops and Chaoborus) appeared to be unaffected.

The authors noted that it would be surprising if Dollar Lake maintained resultant improvements in clarity and low productivity because the lake still received some septic drainage and a large amount of storm water.

REFERENCES: Kennedy and Cooke (1974)

SWEDISH STUDIES

LAKE NAME: Lake Langsjon
LOCATION: Stockholm, Sweden
SURFACE AREA: 35 ha
MAXIMUM DEPTH: 3.5 m

PROBLEM: High content of nutrients. Algal blooms. Fishkills caused by oxygen depletion during the winter. Earlier recipient for municipal wastewater.

RESTORATION OBJECTIVE: To limit the planktonic algal growth and to improve the dissolved oxygen conditions during the winter by reducing the phosphorus concentration.

RESTORATION METHODOLOGY: The lake was treated with aluminum sulphate on April 1968 and May, 1970 at a rate of 50-60 gm/m^3 (approximately $4,000 U.S.A.) each time. About 33.5 tons of chemical were used.

RESULTS: The phosphorus concentrations were reduced only temporarily by the treatments. The 1968 application caused an 80% reduction in phosphorus levels; however, following heavy runoff in spring, 1969 the concentrations were only 40% below the original values and by May, 1970 just 25%. This increase may at least be partly due to unidentified sewage outlets. The winter dissolved oxygen conditions have improved since treatment; there has been a decrease in the number of days of anaerobiosis. Although the phytoplankton volume may not have been affected, certain qualitative changes were evident. Phosphate release from the sediments have also been reduced.

REFERENCES: Blomquist et al (1971), Carlson (pers. comm.) Cronholm (pers. comm.), Jernelov (per. comm.) Jernelov (1970).

pH ADJUSTMENT

DEFINITION

With respect to acid-sensitive oligotrophic lakes pH adjustment is accomplished by the addition of calcium hydroxide ($Ca(OH)_2$) and/or calcium carbonate ($CaCO_3$) to offset acidic conditions (raise pH), re-establish buffer systems and induce suitable improvements in water quality in order to establish a well balanced aquatic ecosystem.

TECHNIQUE

Chemicals are applied to the lake via a flash slurrying device installed on board a boat. The device basically consists of a small bowl like mixing chamber and several lengths of pipe. Lake water is tangentially injected into this chamber using a fire pump while dry chemicals are simultaneously fed into the chamber via a large hopper. The slurry so generated is then discharged into the backwash of a boat.

CANADIAN STUDIES

LAKE NAME:	Middle Lake Hannah Lake Lohi Lake Clearwater Lake
LOCATION:	Sudbury area, Ontario
SURFACE AREA:	21 ha (Middle) 18 ha (Hannah) 29 ha (Lohi) 77 ha (Clearwater)
MAXIMUM DEPTH:	14 (Middle) 7.5 (Hannah) 17 (Lohi) 19 (Clearwater)

PROBLEM: Atmospheric inputs of sulphur dioxide resulted in unusually low pH, high sulphate and heavy metal concentrations and concomitant declines in fish populations.

RESTORATION OBJECTIVE: To artificially re-establish a buffer system in selected acid lakes such that the water quality is suitable for a reproducing fish population.

RESTORATION METHODOLOGY: Hannah and Clearwater lakes acted as controls while Middle Lake was treated with 22 tons of calcium hydroxide ($Ca(OH)_2$) and 15 tons of calcium carbonate ($CaCO_3$). Lohi Lake was treated with 24.5 tons of calcium hydroxide. Both lakes were treated in the fall of 1973.

Chemicals were applied to the lakes via a flash slurrying device, consisting of a small bowl-like mixing chamber and several lengths of pipe installed on a boat. Lake water was tangentially injected into this chamber using a high pressure fire pump, while dry chemicals were simultaneously fed into the chamber via a hopper. A larger diameter pipe then discharged the slurry into the backwash of the boat. Approximately 7,260 kg (8 tons) could be applied to a lake in an average working day using one 16' boat and a five man crew (two onshore, two loading hopper on boat, one driver).

RESULTS:

1. Liming has proven to be a simple, relatively inexpensive tool to neutralize acidic lake conditions and re-establish a weak buffer system in a controlled and predictable manner in the lakes investigated to date.

2. The technique significantly reduces copper and nickel levels in the water column, probably by a precipitation mechanism.

3. Treatment with calcium carbonate ($CaCO_3$) in addition to calcium hydroxide ($Ca(OH)_2$) provides a carbonate reservoir and maintains a more stable buffer system. The carbonate-treated lake (Middle) continues to maintain a neutral pH and lower copper and nickel levels than Lohi Lake ($Ca(OH)_2$ only added).

4. Open water microbial populations generally showed a rapid, positive response to lime addition in both treated lakes. Sediment populations remained relatively constant.

5. Phytoplankton standing stocks showed a positive response to the improved water quality, increasing fivefold in treated lakes during the summer following liming as compared to a doubling in the control lakes. A shift in species dominance from green algae and flagellates to yellow green algae (Chrysophceae) occurred indicating a return to a situation more typical of unstressed Shield lakes. A similar shift occurred in control lakes but to a lesser extent.

6. Zooplankton standing stocks declined in the treated lakes the summer following liming, probably due to a lethally rapid pH change at the time the dominant zooplankton, Cladocera, was laying overwintering eggs. This reduced the following spring cohort. However, as sufficient food is available, it is expected that zooplankton numbers will increase in following seasons.

7. Similarly, the zoobenthic population decline in the treated lakes is probably due to an interruption of the life cycle of the dominant organism, midge (Chironomidae), caused by the sudden pH change. It is expected that numbers will return in response to available food and improved water conditions.

8. Evidence from enclosure studies indicates that the biological recovery of the treated lakes may be speeded by artificial fertilization with phosphorus.

REFERENCES: Scheider et al (1975).

WEED HARVESTING

DEFINITION

The mechanical cutting of aquatic macrophytes and subsequent removal of the detritus from the water body in order to optimize uses of recreational lakes suffering from excessive weed growth and do hopefully induce improvements in water quality.

TECHNIQUE

There is a wide variety of weed harvesters many of which are designed in accordance with the specific nuisance aquatic macrophyte to be handled. Weed harvesting processes are basically divided into two components, there is the cutting itself followed by the removal.

CANADIAN STUDIES

LAKE NAME:	Chemung Lake
LOCATION:	Peterborough, Ontario
SURFACE AREA:	1,646 ha (North Chemung)
	858 ha (South Chemung)
MAXIMUM DEPTH:	6.71 m (North Chemung)
	6.10 m (South Chemung)

PROBLEM: Extremely heavy growth of submerged aquatic vegetation in southern Chemung Lake covering an area of some 430 ha. or about 50% of the lake area.

RESTORATION OBJECTIVE: Harvest the macrophytes in southern Chemung Lake for the purpose of assessing the effects of large scale aquatic vegetation removal on water quality, phytoplankton and macrophyte dynamics and the fisheries.

RESTORATION METHODOLOGY: A mechanical harvester was used to cut and remove the vegetation. The program was initiated in southern Chemung Lake in 1973 following two years of preliminary studies.

RESULTS: Harvesting operations resulted in the removal of 2130 tons (1.93×10^6 kg) of vegetation over an area of 650 acres (260 ha). Harvesting rates averaged 0.37 acres/hr., based on active cutting time. Down time represented 26.2% of the total hours worked and was largely due to inclement weather conditions and mechanical failures. Chemical analyses indicated that the aquatic plant products had nutritional values similar to alfalfa. Processed aquatic plants were evaluated using chickens and sheep and were found acceptable to

the test animals, although the high ash content interferred with digestability. Current studies are concerned with feeding of steers with silage prepared from a combination of milfoil and waste paper. Weight gains to date are extremely promising. In other studies the vegetation was readily composted in an 8 day period. Preliminary greenhouse trials with the composted material demonstrated the value of the product as a plant growth media.

In terms of effect on water quality, no undesirable environmental effects of the harvesting program have been observed.

REFERENCES: Wile and Neil (1975), Wile (pers. comm.)

AMERICAN STUDIES

LAKE NAME: Beulah Lake
LOCATION: East Troy, Wisconsin
SURFACE AREA: 4.5 km^2
MAXIMUM DEPTH: -

PROBLEM: Heavy growths of rooted vegetation, in particular powdered (Potamogeton), coontail (Ceratophyllum), milfoil (Myriophyllum) and Chara.

RESTORATION OBJECTIVE: To harvest the vegetation for nutrient removal and increased usability of the lake.

RESTORATION METHODOLOGY: A mechanical harvester was used to remove the vegetation.

RESULTS: Since 1971 6.5×10^5 kg (wet weight) of vegetation were removed, containing 717 kg of nitrogen and 292 kg of phosphorus. Three years of removal reduced the in-lake phosphate concentration by 0.125 mg/l (80%) and the nitrate concentration by 0.05 mg/l (39%).

REFERENCES: East Troy Sanitary District No. 1 (1971).

LAKE NAME: Sallie Lake
LOCATION: Becker Co., Minnesota
SURFACE AREA: 4.9 km^2
MAXIMUM DEPTH: 17 m

PROBLEM: Blue-green algal blooms; over abundant macrophytes; diurnal oxygen depletion; and occasional fishkills; eutrophic conditions stem from the influx of secondary sewage treatment effluent.

RESTORATION OBJECTIVE: To determine if the full-scale harvest of macrophytes could reduce substantially the nutrient content of the lake.

RESTORATION METHODOLOGY: Full-scale harvest of macrophytes began in late June, 1970 and continued (8 hrs/day) until September 30. Approximately one third of the lake's surface area (littoral zone) was cut over repeatedly. Phosphorus and nitrogen removal in the form of macrophytes and fish were compared to the input of these nutrients based on a detailed nutrient budget. Planning has also been completed for nutrient removal from the wastewater effluent entering the lake.

RESULTS: Harvest of 428.5 metric tons (net weight) of macrophytes removed only 99.5 kg of phosphorus and 715.5 kg of nitrogen. Fish harvest removed almost three times as much phosphorus and twice as much nitrogen. Macrophyte harvest removed only 1.03% of the phosphorus which entered the lake.

REFERENCES: Neel (pers. comm.), Neel et al (1973), Peterson (pers. comm.), Peterson et al (1973), Rogstad (pers. comm.).